Optics Communications 342 (2015) 79–82

Contents lists available at ScienceDirect

Optics Communications

journal homepage: www.elsevier.com/locate/optcom

Annealing and quenching effect in the localized states emission on nanosilicon fabricated by pulsed laser

Wei-Qi Huang [a,*], Shi-Rong Liu [b], Ti-Ger Dong [a], Gang Wang [a], Cao-Jian Qin [b]

[a] Institute of nanophotonic physics, Guizhou University, Guiyang 550025, China
[b] State Key Laboratory of Ore Deposit Geochemistry Institute of Geochemistry, Chinese Academy of Science Institute of Geochemistry, Guiyang 550003, China

ARTICLE INFO

Article history:
Received 25 October 2014
Received in revised form
27 November 2014
Accepted 14 December 2014
Available online 16 December 2014

Keywords:
Laser annealing
Annealing and quenching effects
Plasmonic lattice structure
Nanosilicon

ABSTRACT

Plasmonic lattice structure induced by pulsed laser was observed in the Talbot reflection effect image, which could be used to fabricate nanostructures on silicon. It is interesting that annealing and quenching effects obviously affect the localized states emission on nanosilicon prepared by pulsed laser, in which the annealing parameters are important, such as temperature and time. It is found that the laser annealing is a good way to replace the traditional annealing way in furnace, especially for rapidly annealing. A physical model is made to explain the annealing and quenching effects in the localized states emission on nanosilicon.

1. Introduction

The challenge has been to develop an efficient silicon-based light device because of extremely low emission efficiencies in the indirect band gap of silicon. Recently the photoluminescence (PL) of nanosilicon has been discussed intensively. Silicon-based nanostructures with controlled composition and dimensions attract considerable interesting for novel applications in optoelectronics [1,2], including chip-laser [3,4], light emitting diodes (LEDs) [5–7], and solar cells [8]. Many methods have been used to prepare silicon nanostructures with specific tailored properties, such as magnetron sputtering [9], chemical vapor deposition [10], pulsed laser etching (PLE) and pulsed laser deposition (PLD) [11–14], in which the annealing is very important in the preparing process for improving efficiency in the defect states emission and the localized states emission [15–17]. It is noted that a terrace step structure is formed due to annealing [18] and a new kind of interface state occurs after annealing [19], which could affect the localized states emission.

In the article, it is interesting that plasmonic lattice structure induced by pulsed laser was observed in the Talbot reflection effect image in fabricating nanostructures on silicon. The annealing and quenching effects in the localized states emission are investigated on silicon nanostructures prepared by pulsed laser. In the annealing or quenching process, taking suitable parameters, such as temperature and time, could produce some nanostructures to form the localized states in band gap for higher efficient emission. It is found that laser annealing may be a good way to replace the conditional furnace annealing in the preparing process.

A pulsed Nd:YAG laser (wavelength: 1064 nm, pulse width (FWHM): 20 ns, repetition rate: 1–4 kHz) is used to prepare silicon nanostructures. In the preparing process, nanosecond (ns) pulse laser induces plasma ($\omega^2=Ne^2/m\varepsilon$ [20], N is electronic density and ε is dielectric function), which forms a resonant standing wave in the cavity where the plasmonic wave is built ($\omega_q{}^2=(2\pi Ne^2/m)q+(3/4)q^2(hk_f/2\pi m)^2$, k_f: vector; q: quantum number of plasmon). Here, the plasmonic lattice structures induced by ns pulsed laser could be observed in the reflection Talbot effect image amplified, which is used to fabricate micro-nanostructures on silicon, as shown in Fig.1.

By the reflection Talbot amplifying, Fig. 1(a) shows the period pattern provided by interaction between plasmon and photon in the cavity ablated by the beam of the third harmonic of a ns pulse Nd:YAG laser (355 nm), in which blue light image of the plasmonic standing wave with the resonant modes in the cavity is observed by eyes directly on the screen (lattice constant is about micrometer). The infrared image of the diffraction pattern on the plasmonic lattice structure induced by pulsed laser at 1064 nm in the cavity is shown in Fig. 1(b), which may be similar with Wigner crystal structure. Fig. 1(c) shows a kind of hole-net silicon structure in scanning electron microscope (SEM) image on cavity wall due to the plasmonic wave affection, and Fig. 1(d) shows the cavities array in optical microscope image, in which the points

* Corresponding author.
E-mail address: WQHuang2001@yahoo.com (W.-Q. Huang).

http://dx.doi.org/10.1016/j.optcom.2014.12.041
0030-4018/

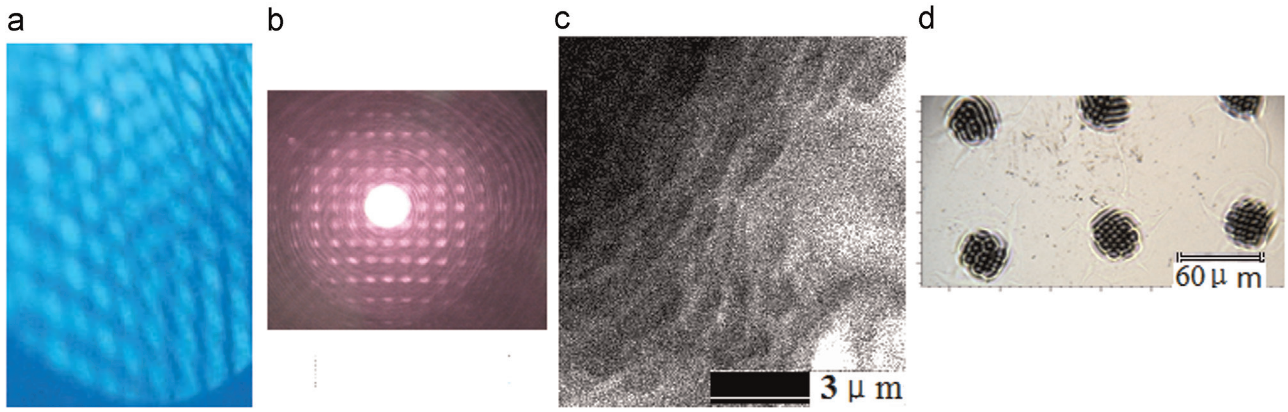

Fig. 1. (a) Period pattern image of plasmonic standing wave in the cavity by the reflection Talbot amplifying; (b) Infrared image of the diffraction pattern on the plasmonic lattice structure induced by pulsed laser at 1064nm in the cavity; (c) A kind of hole-net silicon structure in scanning electron microscope (SEM) image on cavity wall due to the plasmonic wave affection; (d) Cavities array in optical microscope image, in which the points array structures in every cavity are remained after the affection of the plasmonic lattice wave.

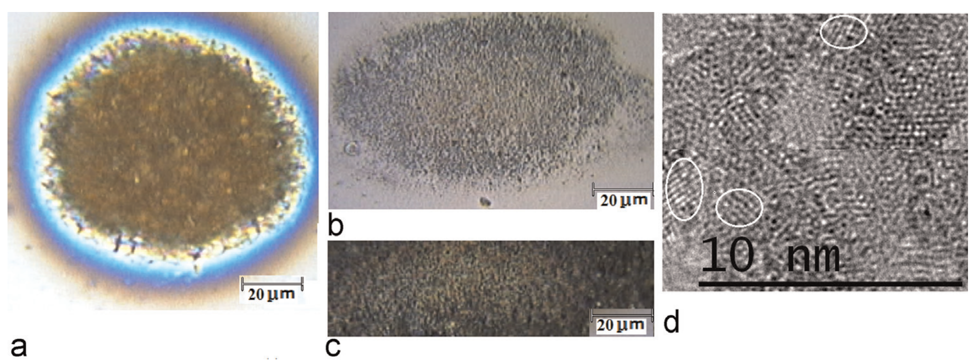

Fig. 2. (a) A kind of forested structure (optical microscope image) prepared by ns pulse laser on silicon in air; (b) Smoother silicon forested structures (optical microscope image) in nitrogen gas blowing; (c) Smoother silicon forested structures (optical microscope image) in oxygen gas blowing; (d) Transmission electron microscope (TEM) image of silicon quantum dots structure on the nanosilicon sample prepared by ns pulsed laser in oxygen after annealing at 1050 °C for 20 min.

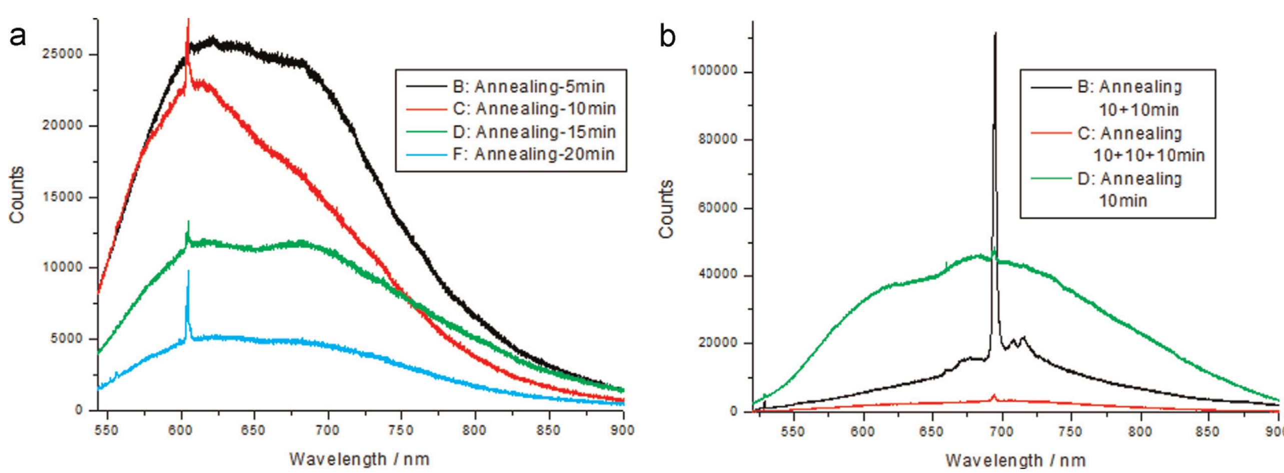

Fig. 3. (a) PL spectra under excitation of laser at 514 nm with changing annealing time at 1050 °C on the nanosilicon sample prepared by ns pulse laser in 1 Pa oxygen atmosphere; (b) PL spectra under excitation of laser at 514 nm, in which annealing time is kept for 10 min in each time of twice annealing at 1050 °C on the nanosilicon sample prepared by ns pulsed laser in 100 Pa oxygen atmosphere.

array structures in every cavity are remained after the affection of the plasmonic lattice wave.

The silicon micro-nanostuctures prepared by pulsed laser need to be activated for emission by annealing. Fig. 2(a) (optical microscope image) shows a kind of forested structure prepared by ns pulse laser on silicon in air, which is similar with black silicon. The silicon forested structures become smoother in nitrogen gas blowing (Fig. 2(b) (optical microscope image)) or in oxygen gas blowing (Fig. 2(c) (optical microscope image)) after annealing at 1050 °C for 20 min. In Fig. 2(d), the transmission